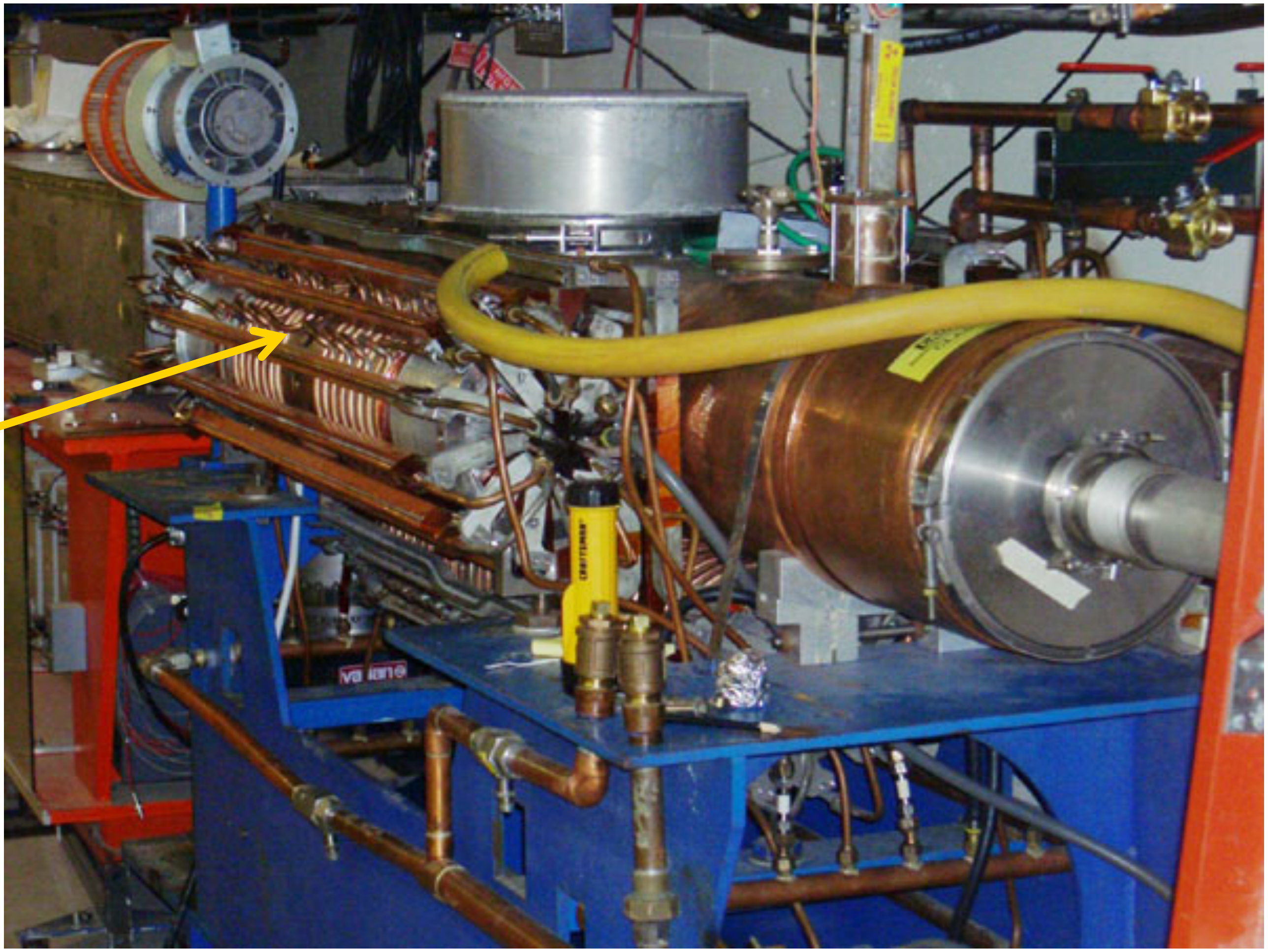
New Ferrite Cores for Booster RF Cavity Tuners (Proton Improvement Plan)

Ralph J. Pasquinelli

Fermilab

November 23, 2011

Ferrites for Booster Tuners

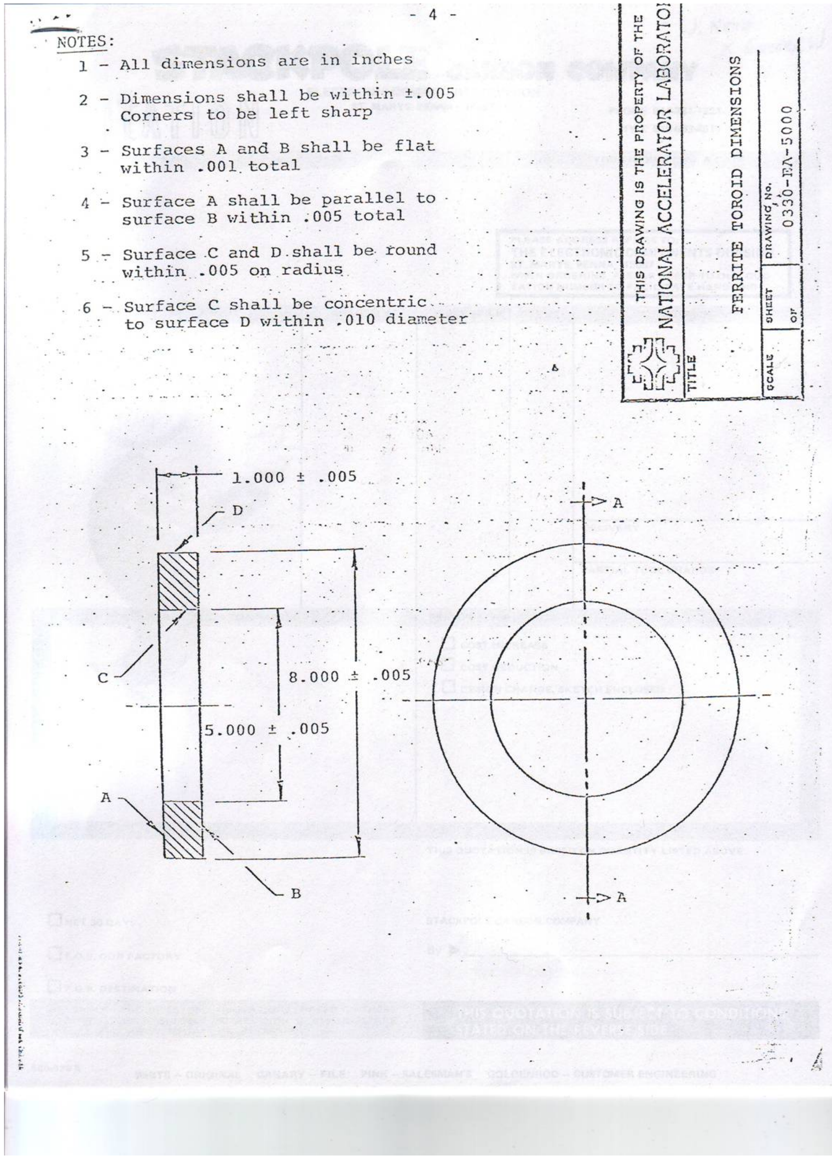


One of Three Tuners

Issues with Booster Tuners

- *Booster tuners close to 40 years old*
- *28 cores per tuner, three tuners per cavity*
- *Spare tuners in short supply*
- *All booster cavities to be refurbished over next 18 months*
- *Rebuilds are tedious, cores are succeptible to breakage, water leaks, radioactive*
- *Locate companies that can still produce cores of the required size, permiability, and Q*

Ferrites for Booster Tuners



Nickel-Zinc
8 inches OD
5 inches ID
1 inch thick
Two values of μ

Ferrites for Booster Tuners

National Magnetics Group

STACKPOLE

Fair-Rite Products Corp.
Your Signal Solution ®

Ceramic Magnetics, Inc.
A THOMAS & SKINNER COMPANY

FERROXCUBE
A YAGEO COMPANY

TOSHIBA

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Ferrites for Booster Tuners

Ceramic Magnetics, Inc.
A Thomas & Skinner Company

N40 — High Frequency Ni-Zn Ferrite

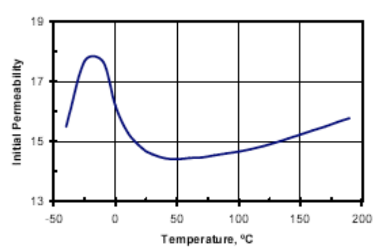
N40 is a Ni-Zn ferrite containing cobalt which has a suitable Q for inductive devices in the 1 to 100 MHz frequency range.

Typical Properties

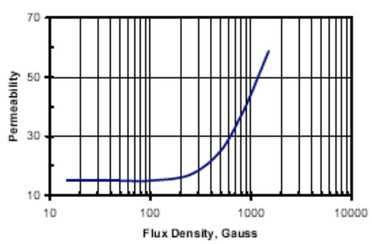
Initial Permeability	15
Saturation Flux Density	2500 Gauss
Remanent Flux Density	950 Gauss
Coercive Force	8.0 Oersted
Curie Temperature	600°C
dc Volume Resistivity	10^{10} ohm-cm
Bulk Density	4.80 g/cc

Unless otherwise specified, all tests were performed at 10 KHz, 22°C
Bs, Br, Hc tested at 1 KHz, 40 Oersted

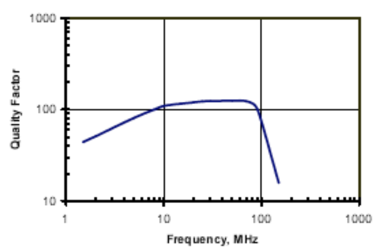
Initial Permeability vs. Temperature



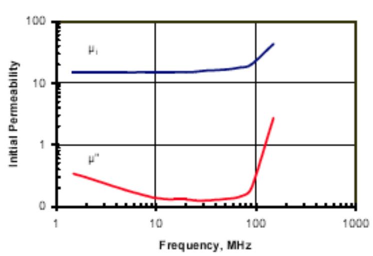
Permeability vs. Flux Density



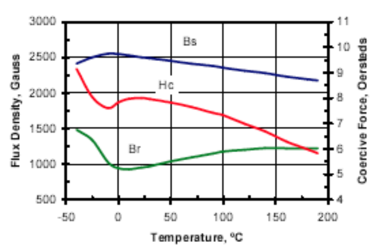
Quality Factor vs. Frequency



Complex Permeability vs. Frequency



BH Loop Parameters vs. Temperature



Upon first delivery
Low Q (<20) due to
Skipped heat treating
Returned and baked
μ is reduced by heat

μ=15
Measured μ=11
Q>800 @ 43 MHz

Can make μ=20
by adjusting formula

Ferrites for Booster Tuners

NATIONAL MAGNETICS GROUP, INC.

MANUFACTURERS OF MAGNETIC AND ADVANCED MATERIALS

AFFILIATE: TCI CERAMICS, INC.

M3

Material

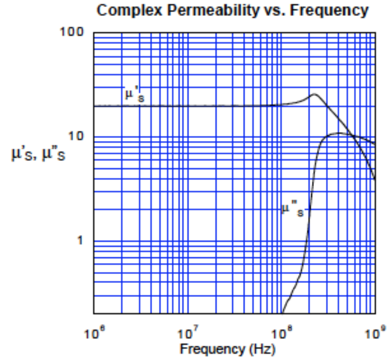
A perminvar NiZn ferrite designed for high frequency applications (up to 100 MHz) including broadband transformers, antennas and high Q inductors.

Specifications

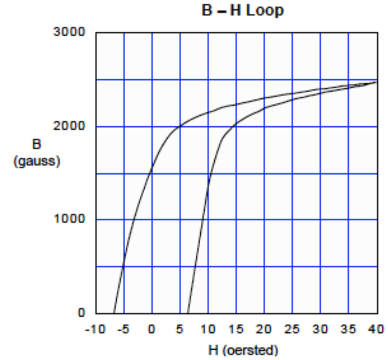
Property	Unit	Symbol	Standard Test Conditions	Value
Initial Permeability		μ_i	Frequency=10 kHz; B<10 gauss	$20 \pm 20\%$
Saturation Flux Density	gauss	B_S	H=40 oersted	≈ 2500
Residual Flux Density	gauss	B_r		≈ 700
Coercive Force	oersted	H_C		≈ 7
Loss Factor	10^{-6}	$\tan\delta/\mu_i$	Frequency=100 MHz; B=1gauss	≤ 500
Temperature Coefficient of Initial Permeability (20-70°C)	%/°C			≤ 0.15
Volume Resistivity	Ω cm	ρ		$\approx 10^7$
Curie Temperature	°C	T_C		> 500

Note: values are typical and based on measurements of a standard toroid at 25 °C

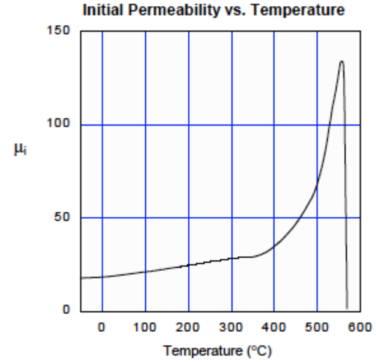
Complex Permeability vs. Frequency



B – H Loop



Initial Permeability vs. Temperature



μ=20

Measured μ=15.5

Q>1000 @ 40 MHz

Ferrites for Booster Tuners

NATIONAL MAGNETICS GROUP, INC.

MANUFACTURERS OF MAGNETIC AND ADVANCED MATERIALS

AFFILIATE: TCI CERAMICS, INC.

M4

Material

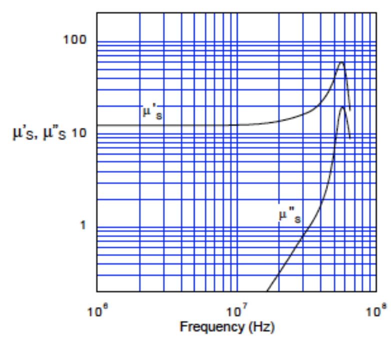
A NiZn ferrite designed for high frequency applications including transformers, antennas and resonant circuit inductors.

Specifications

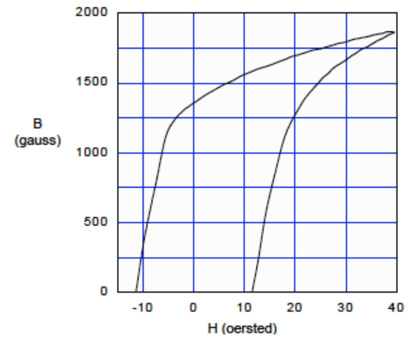
Property	Unit	Symbol	Standard Test Conditions	Value
Initial Permeability		μ_i	Frequency=10 kHz; B<10 gauss	12.5 ± 20%
Saturation Flux Density	gauss	B_S	H=40 oersted	≈ 1800
Residual Flux Density	gauss	Br		≈ 1350
Coercive Force	oersted	H_C		≈ 12
Loss Factor	10^{-6}	$\tan\delta/\mu_i$	Frequency=10 MHz; B=1gauss	≤ 850
Temperature Coefficient of Initial Permeability (20-70°C)	%/°C			≤ 0.45
Volume Resistivity	Ω cm	ρ		≈ 10^9
Curie Temperature	°C	T_C		> 500

Note: values are typical and based on measurements of a standard toroid at 25 °C

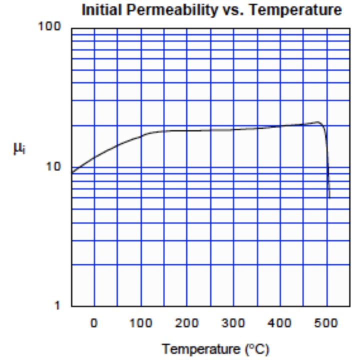
Complex Permeability vs. Frequency



B – H Loop



Initial Permeability vs. Temperature



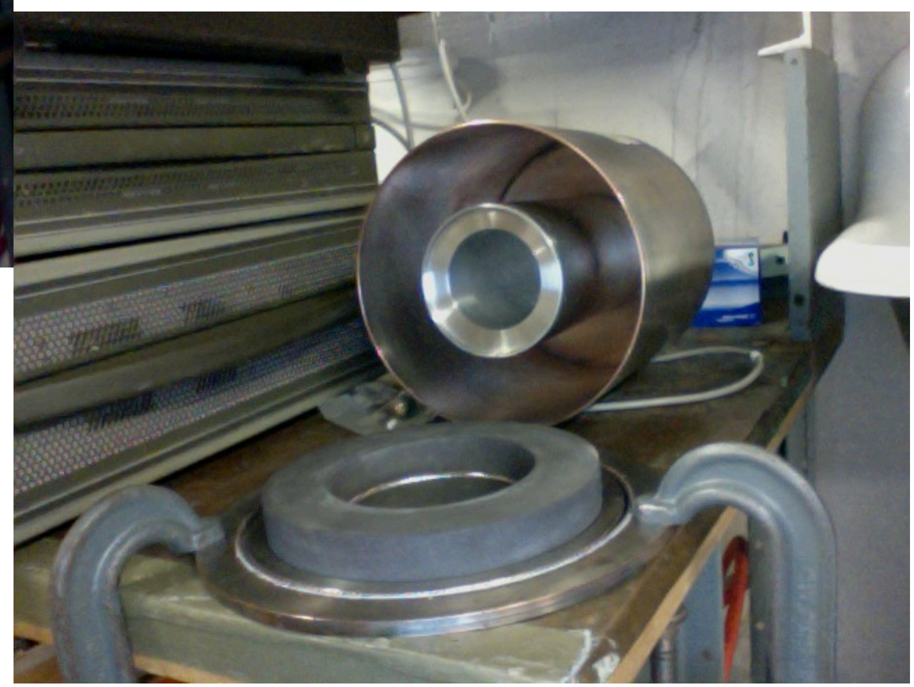
μ=12

Measured μ=11

Q>280 @ 44 MHz

Ferrites for Booster Tuners

Coaxial Test Fixture



Measure Q,L, and μ

Ferrites for Booster Tuners

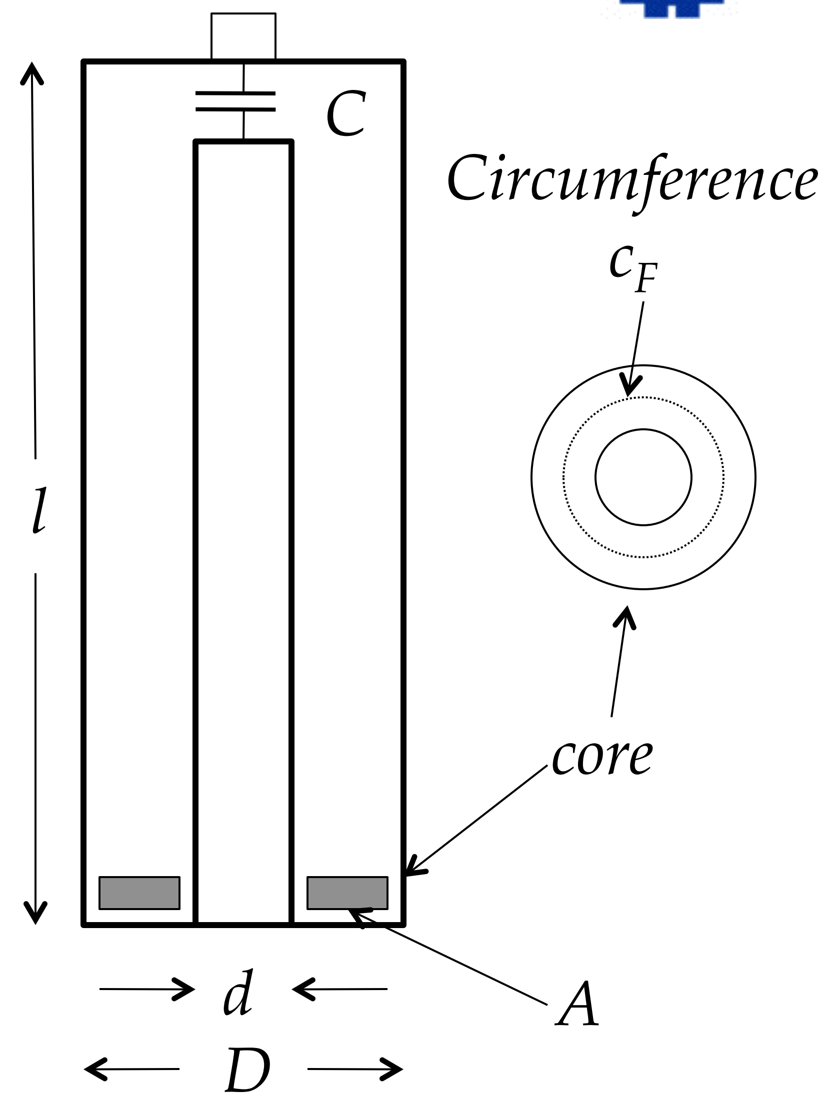
Coaxial Test Fixture

$$L_{coax} = \frac{\mu_o * l}{2\pi} * \ln\frac{D}{d}$$

$$Q = \frac{f_o}{f_{-45} - f_{45}}$$

$$L_F = \frac{1}{(2\pi * f_o)^2 * C}$$

$$\mu_F = \frac{L_F * c_F}{\mu_o * A}$$

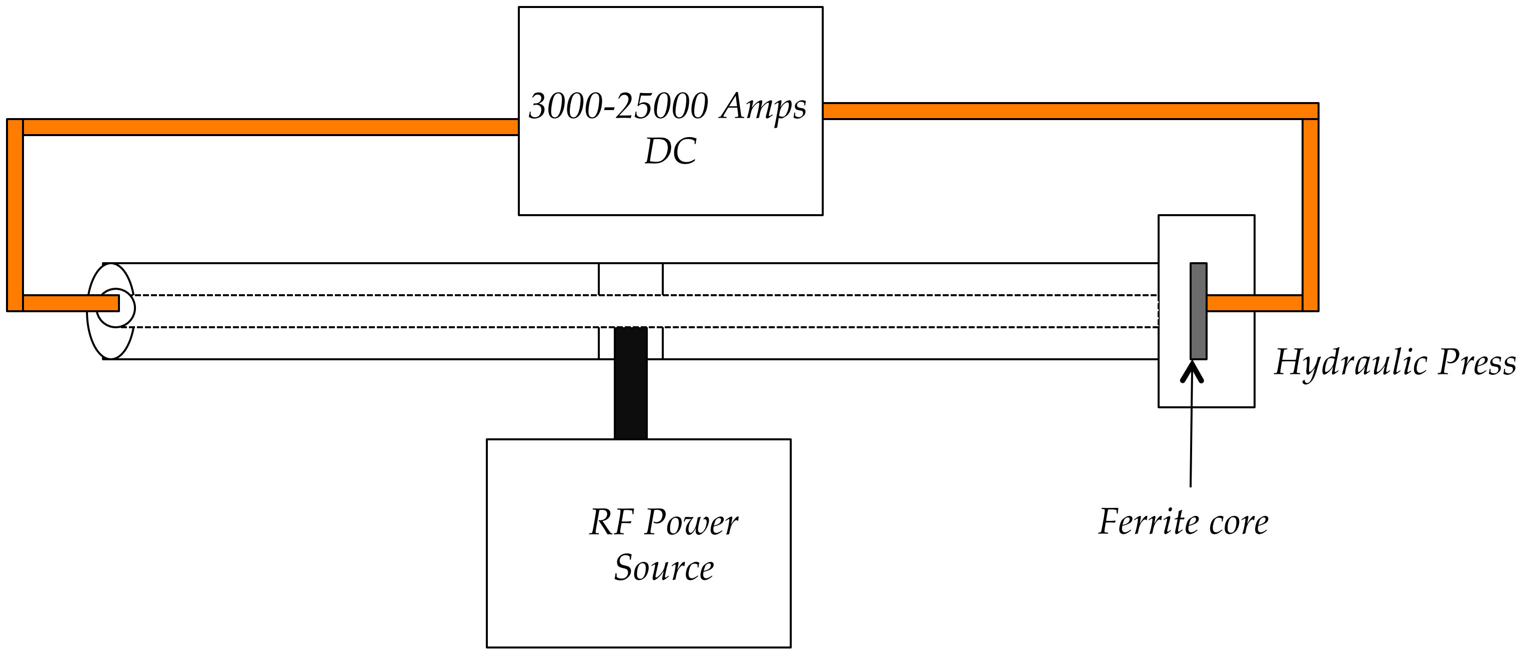


R. J. Pasquinelli

Ferrites for Booster Tuners

40 Year Old Biased Core Tester

Ferrites for Booster Tuners



Ferrites for Booster Tuners

Measured with HP Vector Impedance (VI) meter and external synthes

Core #	Manufacturer	data sheet mu	measured mu	Qo	fo MHz	f low	f high	Zo angle 0 deg	low Z +45 deg	high Z -45 deg	Inductance
1	N40 Ceramic magnetics	15	11.49	767	43.1283	43.1005	43.1567	16000	10200	9900	2.69E-08
2	N40 Ceramic magnetics	15	11.51	847	43.1134	43.0926	43.1435	16200	10600	10900	2.70E-08
3	N40 Ceramic magnetics	15	11.27	866	43.3138	43.2933	43.3433	14900	9680	9850	2.64E-08
4	N40 Ceramic magnetics	15	11.63	947	43.0081	42.9895	43.0349	15600	10200	10800	2.73E-08
5	N40 Ceramic magnetics	15	11.46	823	43.1498	43.1289	43.1813	16500	10800	11200	2.69E-08
6	N40 Ceramic magnetics	15	11.44	1016	43.1705	43.1543	43.1968	16600	10700	11500	2.68E-08
7	N40 Ceramic magnetics	15	11.91	1041	42.7768	42.7613	42.8024	16800	11000	11800	2.79E-08
8	N40 Ceramic magnetics	15	11.88	839	42.8005	42.7814	42.8324	17000	11200	11800	2.78E-08
9	N40 Ceramic magnetics	15	11.26	811	43.3221	43.2997	43.3531	17000	11000	11700	2.64E-08
10	N40 Ceramic magnetics	15	11.61	1044	43.025	43.0092	43.0504	17100	11100	11600	2.72E-08
1	M3 National magnetics	20	15.32	509	40.1985	40.1386	40.2175	22000	14400	14500	3.59E-08
2	M3 National magnetics	20	15.93	1198	39.7838	39.7688	39.802	21000	14000	14480	3.74E-08
3	M3 National magnetics	20	15.63	1102	39.9918	39.9785	40.0148	19300	13600	13920	3.66E-08
4	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
5	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
6	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
7	M3 National magnetics	20	#DIV/0!	#DIV/0!							#DIV/0!
8	M3 National magnetics	20	15.43	1160	40.123	40.1109	40.1455	19400	13700	13900	3.62E-08
9	M3 National magnetics	20	14.47	1063	40.8016	40.7883	40.8267	18800	13300	13300	3.39E-08
10	M3 National magnetics	20	12.45	1001	42.3315	42.3161	42.3584	18140	12500	12220	2.92E-08
11	M4 National magnetics	12	10.95	286	43.593	43.5177	43.6703	4620	3160	3240	2.57E-08
12	M4 National magnetics	12	11.04	286	43.5173	43.4412	43.5931	4600	3140	3250	2.59E-08
13	M4 National magnetics	12	10.88	289	43.65	43.575	43.7258	4660	3160	3250	2.55E-08
14	M4 National magnetics	12	11.11	283	43.4561	43.3798	43.5335	4560	3090	3200	2.60E-08
15	M4 National magnetics	12	11.04	293	43.517	43.4441	43.5924	4620	3180	3240	2.59E-08
16	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
17	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
18	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
19	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!
20	M4 National magnetics	12	#DIV/0!	#DIV/0!							#DIV/0!

Ferrites for Booster Tuners

Status & Future Plans

- *First set of sample cores delivered and tested at low level*
- *Refurbish 40 year old biasing test jig and test cores*
- *Build a new tuner using new cores and test*
- *Determine how many new tuners are desired*
- *Procure additional cores for new tuners*
- *Assign appropriate resources (AD & TD) to build and test tuners*